

*Citation for published version:*

Lindgren, J & Emmitt, S 2017, 'Diffusion of a systemic innovation: a longitudinal case study of a Swedish multi-storey timber housebuilding system', *Construction Innovation: Information, Process, Management*, vol. 17, no. 1, pp. 25-44. <https://doi.org/10.1108/CI-11-2015-0061>

*DOI:*

[10.1108/CI-11-2015-0061](https://doi.org/10.1108/CI-11-2015-0061)

*Publication date:*

2017

*Document Version*

Peer reviewed version

[Link to publication](https://doi.org/10.1108/CI-11-2015-0061)

The final publication is available at Emerald via <https://doi.org/10.1108/CI-11-2015-0061>.

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**Diffusion of a systemic innovation:  
A longitudinal case study of a Swedish multi-storey timber  
housebuilding system**

Journal:	<i>Construction Innovation: Information, Process, Management</i>
Manuscript ID	CI-11-2015-0061.R2
Manuscript Type:	Research Article
Keywords:	Systemic innovation, Diffusion, Timber construction, Multi-Storey Housebuilding, Case Study, Sweden

**Diffusion of a systemic innovation:  
A longitudinal case study of a Swedish multi-storey timber housebuilding system**

**Abstract**

**Purpose** – The purpose is to identify factors that influence the diffusion of a systemic innovation in the Swedish construction sector. The focus is on high-rise multi-storey timber housing; the development of which was enabled by a change in building regulations. This allowed building higher than two stories in timber.

**Design/Methodology/Approach** – A longitudinal case study was used with multiple data collection methods to study the development and diffusion of a multi-storey timber house system by a case study organisation.

**Findings** – The findings contribute to understanding for a number of interacting factors influencing the diffusion of a systemic innovation related to the case study organisation.

**Originality – value** - The research provides a holistic view of interacting factors influencing the diffusion of a systemic innovation. The results have value to the Swedish construction sector as well as to the global community of construction researchers since it provides empirical findings that further increase the understanding for diffusion of systemic innovations in a specific context.

**Keywords:** Case Study, Diffusion, Multi-Storey Housebuilding, Sweden, Systemic innovation, Timber construction.

**Paper type:** Research paper

**Introduction**

Technological innovation in building is of interest to a wide range of stakeholders, from clients to product manufacturers, designers, contractors and building users (Bowley, 1960, Bowley, 1966, Slaughter, 1998, Slaughter, 2000, Håkansson and Ingemansson, 2012); as well as for governments aiming to improve a nation's competitive advantage (Lundvall *et al.*, 2002, Porter, 2011, Barrett and Sexton, 2006). A variety of starting points and influences exist, and also differ, in relation to the context of the innovation; the structure of production, industry relationships, procurement systems, regulatory conditions and organisational resources (Rose and Manley, 2014). Gann *et al.* (1998) identified changes in regulations as a starting point for innovation, which is valid for the research reported in this article. A change in the Swedish building regulations in 1994 for houses with more than two storeys was our starting point. The regulations changed to become performance-based, with no height limitations as long as buildings met functional performance requirements (Boverket, 2014). This enabled multi-storey houses to be constructed in timber in Sweden (Engström and Hedgren, 2012). Since 1994 the number of actors active in timber based multi-storey housing has increased and building methods have evolved. According to some, the use of timber has increased significantly (SFIF, 2012) while others conclude that the market share of different materials remains the same (Andersson and Larsson, 2014). Despite this apparent confusion, timber has become a viable, low-carbon, alternative to concrete and steel in Sweden. As an example, one of the larger names in timber multi-storey construction has received an order for 2000 apartments (Bengtsson, 2014). The change in regulations has challenged an established market and opened up potential for innovation in the Swedish construction

sector. Mahapatra *et al.* (2012) study on multi-storey buildings in timber showed that Sweden had the most favourable conditions for market growth followed by the UK and Germany, which makes Sweden interesting from a diffusion point of view.

The focus for the research reported here relates to the attempts made by a case study organisation (CSO) to diffuse multi-storey buildings in timber on the Swedish market. The characteristics of this innovation are quite complex, involving, for example, changes in building technologies, organisational structures and market dynamics. Given its effects on the construction process and changes in the building system, 'systemic' innovation (Colvin *et al.*, 2014) describes the phenomenon being researched as the innovation diffuses within Sweden. The objective was to identify factors that influence the innovation diffusion process. To achieve this objective the development and construction of timber multi-storey buildings by an established timber producer was researched via a longitudinal study.

### Innovation diffusion

The diffusion of innovations, i.e. communicating a new idea through certain channels (Rogers, 2003) is a key activity in the innovation process. It relates to the adoption and diffusion of new ideas, methods and products within a social system (Howaldt *et al.*, 2010, OECD, 2005, Rogers, 2003). According to Rogers, the decision-making process of an individual consists of five stages; (1) knowledge, where awareness and knowledge about the innovations arises; (2) persuasion, where a favourable or unfavourable attitude is formed about the innovation; (3) decision, where decisions about adoption of the innovation takes place; (4) implementation and finally (5) confirmation, which is about reinforcing the decision already made. Diffusion happens when several individuals go through the decision-making process over time. Although described in a linear fashion, a lot of activities and events happen during this process. For example, in the implementation stage innovations can be changed or modified (labelled as re-invention) and after adoption an innovation can be rejected (labelled discontinuance). Rogers (2003) also makes a distinction about diffusion in organisations, where the process is much more complex because it involves a number of individuals that play a role in different types of decision-making. Rogers classifies these decisions into activities leading to the decision to adopt (agenda-setting and matching) and implementation (redefining/restructuring, clarifying and routinising). As can be seen, the innovation is modified and reinvented in the implementation phase. In addition, Rogers also has an extensive view of what should be included in diffusion studies. For instance, Rogers states that consequences of the diffusion are an important part of diffusion studies and that this part often is neglected in diffusion studies. A deeper understanding is also emphasised by Tidd (2010), who says that more attention is required to gain a better understanding for why and how innovations are adopted., which implies the need for longitudinal research.

Rogers' work was primarily concerned with providing a comprehensive and generic model of the diffusion of innovations. However, different sectors may have unique characteristics influencing diffusion (Widén and Hansson, 2007) highlighting the need for sector specific research to provide a deeper understanding for diffusion. A comprehensive review of the literature also reveals a need for more diffusion research in

construction, as confirmed by Rose and Manley (2014). A significant characteristic of the construction industry that influences diffusion is that it is project based, often with a short economic perspective and short-term relationships (Widén and Hansson, 2007, Winch, 1998) and in each project new features can arise (Sullivan *et al.* (2010)). Viewing buildings as a system of many interacting components and interacting with its environment implies complexity, since changes in one part can lead to changes in other parts (Winch, 1998, Slaughter, 1998, Widén and Hansson, 2007, Barrett and Sexton, 2006). Buildings can furthermore often only be tested in full scale and have to last for many years (Slaughter, 1998), which also influences diffusion.

In diffusion studies in general and in construction, many diffusion researchers refer to Rogers (2003). An example from construction is Larsen (2005), who builds on Rogers to provide a context specific understanding for how construction actors behave in the early stages of the diffusion process. Research has also studied specific parts of the diffusion process, such as factors influencing adoption decisions. Examples include the price/cost level as a key criteria for adoption (Loosemore and Richard, 2015) with decisions often taken with a short term cost-centred view (Manley, 2006, Ivory, 2005, Sexton *et al.*, 2008). Client behaviour is another influential factor and active clients has been identified as positive for diffusion ((Blayse and Manley, 2004, Loosemore and Richard, 2015, Loosemore, 2014), for example in areas such as setting client requirements, project flexibility and standards of work (Blayse and Manley, 2004). In studies of adoption decisions, risk has been identified as highly influential, especially when associated with involved technologies and longevity (Loosemore and Richard, 2015). Both Larsson (1992) and (Emmitt, 1997) have highlighted exposure to risk in their research into adoption decisions by construction stakeholders. Besides highlighting the importance of the individual's innovation decision-making behaviour, both Emmitt and Larsson state that risk-taking influences the decisions taken within the unstable temporal social network that develops within construction projects. "Safe" choices relating to known products, techniques and ideas are favoured over new ones unless there is a stimulus to change, for example a change in regulations.

Studying specific parts of the diffusion process and individuals' choices and actions provides useful insights. Some studies have also focused on following diffusion processes over the long term relating work to Rogers and innovation diffusion in organisations. Shibeika and Harty (2015) researched diffusion of digital innovation in a project based firm, which provides a thorough description of what happens over time, and shows that diffusion is both time-sensitive and context-specific. Orstavik (2014) also expressed the usefulness of having a long time perspective for the understanding of the innovation of building materials for wet rooms in Norway and how earlier innovations shape descendants (although not viewing a sequence of projects). Gambatese and Hallowell (2011), emphasise the usefulness of a wider perspective of the innovation process, in their case from initiation to outcomes, to provide guidance for improvements of the innovation process. Murphy *et al.* (2015) describe the importance of managing innovation alongside projects. They also emphasize that a post-project review is important to exploit opportunities for re-use, thereby also emphasising the usefulness of viewing several projects and their outcomes and results. These earlier studies emphasise

the usefulness of having a wider perspective of the diffusion of innovations in terms of reviewing several projects over time. These findings stimulated the need to take a longitudinal study of the diffusion processes over the long term to understand how the process takes place over time regarding how it is redefined and restructured. The approach taken in this study should therefore be valid to develop current knowledge about diffusion and relating it to innovation in organisations.

### Systemic innovation, diffusion and influencing factors

The diffusion process has also been discussed in relation to innovation type. In the categorization of construction innovation types several construction researchers (see for instance (Lloyd-walker *et al.*, 2014, Gambatese and Hallowell, 2011, Murphy *et al.*, 2015) refer to work by Slaughter (1998). Slaughter's categorization builds on *the magnitude of change from current state-of-the-art* (pp 227) and *expected linkages of the innovation to other components and systems* (pp 227). Magnitude ranges from incremental to radical and regarding linkages, innovations were categorized as modular, architectural and system innovations. *Modular innovations* relates to a significant change within a component. *Architectural innovations* relates to a small change in a component but with a major change in links to other components and systems. A *system innovation* means integration of multiple independent innovations that must work together to perform new functions or improve the facility performance as a whole.

Taylor (2006) investigated diffusion of architectural innovations, with a special interest on innovation in inter-organisational networks. Taylor used the label systemic innovation meaning "*innovations that reinforce the existing product but necessitate a change in the process that requires multiple firms to change their practice*" (pp 25). Both Taylor and Slaughter refer to Henderson and Clark (1990), who define architectural innovations as "*innovations that change the way in which the components of a product are linked together, while leaving the core design concepts (and thus the basic knowledge underlying the components) untouched*" (pp 10). They pinpoint that components in the system can change as well, and this is often also a trigger for innovation. When discussing different types of innovations there may be difficulties to clearly define one innovation as distinct from another. From this we can conclude that it is not crystal clear what a systemic innovation and other innovations are. Although researchers present a clear definition, they pinpoint that one innovation type might include other innovation types or changes not considered innovation. If the changes are an effect of a number of innovations or if they are just changes (not innovations) in different parts of the construction process is not focused in this research. In line with Taylor (2006), we place a special interest on the inter-organisational effects/consequences from innovations with possible effects on the whole construction process (including its actors and their resources). According to Lindgren (2016) the concept of systemic innovation relates to a systems view from different levels. This establishes a focus on the interaction between different parts of a system within a specific context. Thus the concept of systemic innovation is relevant to innovations that are not considered isolated ideas, products, or practices in the construction process; and was therefore suitable for the innovation type studied in this research.



Returning to different innovation types and their diffusion, construction innovation diffusion research has highlighted incremental innovations as relatively easy to implement, since they carry a low risk, are usually perceived as less complex and affect few parts in the construction process (Taylor and Levitt, 2005, Larsson, 1992). Taylor (2006) has also concluded that systemic innovations have failed to diffuse rapidly or widely and related this to the complexity of systemic innovations, requiring multiple firms to change their processes and/or routines in a coordinated fashion. Sometimes this results in change and redistribution of work between design and construction firms (Taylor, 2006). Other authors also imply complexity in similar terms, for example; systemic innovations as holistic and relational to their nature (Colvin *et al.*, 2014); covering multiple relationships (Powell, 1998); requiring coordination of different parts of the system of which it's embedded in (Maula *et al.*, 2006). Some forms of procurement, such as competitive tendering, does not provide incentives to work with innovations (Winch, 1998, Blayse and Manley, 2004). This can also influence systemic innovations, since innovations must be negotiated with a number of parties (Winch, 1998) and with systemic innovations the number of parties involved can be many. However, a systemic understanding may also have a positive influence on diffusion (Widén and Hansson, 2007), by using development groups with an early objective of filling a recognized need, cross functional development teams, external networks and integration. To conclude, a major influential factor for diffusion of systemic innovations are the effects on other parts, such as actors, relationships, products and processes in a system.

The extent of systemic innovations can also be related to how knowledge is created and exchanged, which is a central part of the innovation process (OECD, 2005). Combining new and previous knowledge, i.e. knowledge integration is a central area and can be achieved in ways through a number of different mechanisms depending on different amounts of social interaction (Van De Ven *et al.*, 1976, Grant, 1996). According to studies by Taylor and Levitt (2005), the flow of inter-organisational knowledge, and hence diffusion, is affected by; organisational variety; the change in population of contractors from project to project; how many different boundaries an innovation spans; and scope. High organisational variety and large span are negative for the diffusion of innovations (Taylor and Levitt, 2005). When the *scope* moves from incremental innovations to systemic innovations, diffusion is affected negatively. This is because with more parties, processes and products that need to be changed, additional knowledge flows and exchanges come into question (Taylor and Levitt, 2005). Gann and Salter (2000) also mean that the discontinuous nature of project based production leads to broken learning and feedback loops or as Blayse and Manley (2004) puts it, discontinuities in knowledge development and knowledge transfer, affecting knowledge flows negatively. With this being an influencing factor from the start, the scope of systemic innovations should imply added complexity.

**Timber based building systems – the Swedish context**

The systemic innovation that was studied was a timber-based multi-storey housing system (hereafter denoted TMHS), and one product of many on the Swedish housing and building market. Multi-storey housing in Sweden is dominated by concrete (Andersson

and Larsson, 2014). For small houses, the market situation is the other way around, with timber dominating the market (TMF, 2016, SCB, 2016). When overviewing TMHS many types exist, for example prefabricated surface elements with or without insulation and sealing coat or as three dimensional volume-elements completed with plumbing, electrical installations, finishing etc. (Mahapatra *et al.*, 2012). TMHS can be open, allowing different complementary solutions (Ågren and Wing, 2014) in the timber frame, or closed, i.e. a total solution for the complete building is set and the solution is closed (Lessing *et al.*, 2015). In the timber high-rise sector in Sweden there are four companies that have well-developed systems. Studies of beliefs and assumptions regarding timber based building systems (Engström and Hedgren, 2012), which has an impact on decision making, have shown that inaccurate beliefs, assumptions and rules-of-thumb form a basis for decisions and thereby constitute an obstacle towards innovation diffusion. Since many decisions are made based on previous experiences and timber is a new alternative, it is the dominating building methods and materials that have an advantage. Hemström *et al.* (2011) also reports that Swedish architects perceive concrete as superior to steel and wood frames with regard to engineering aspects, influencing adoption decisions. For diffusion of timber construction, breaking path dependency of existing and established innovation systems, such as concrete, is needed (Mahapatra *et al.*, 2012). However, there are well-defined systems in timber available on the market. Jansson *et al.* (2014) studied platform use in systems building, and one of the studied platforms was in timber. An interesting characteristic with the system was that it was described as highly standardized and defined, to increase the ability to reuse solutions in different projects, which also is important for industrialised building. In various articles, the four companies above also emphasise the need to work in an industrialised way, and one of the companies clearly emphasise the usefulness of lean-thinking in their development and way of work (Johnsson, 2013). Material from the companies (webpages, YouTube-videos etc.) also shows these characteristics of the systems. They especially show that they erect buildings very fast through a well-defined process. Overall, much of the conducted research in timber and multi-storey buildings relates to industrial building, since the material is very suitable for that type of construction process (Tykkä *et al.*, 2010).

## Research Methodology

The studied innovation is an established material (timber) and product (timber-frame) applied to a new setting (multi-storey construction) by an organisation with the aim to get the innovation adopted and widely diffused in the Swedish market. The innovation can be considered systemic due to its inter-organisational (and intra-organisational) effects in the construction process. This research was conducted as part of a larger research project that addresses knowledge integration in temporary construction projects and building component manufacturers' innovativeness. One of the participating partners in the research projects became the Case Study Organisation (CSO) for this research. Thus the organisation was already selected, which allowed the researchers to discuss various research avenues with the organisation. It was during the initial discussions that the CSO identified the challenges with the TMHS and agreed for it to become the focus of the research reported in this article. The research, therefore, reflects the CSO's response and change in light of its learning experiences towards diffusion. The research addresses our stated need to study systemic innovation diffusion processes over the long term and its



progress over time including implementation and consequences, thereby valid to develop current knowledge about systemic innovation diffusion and innovation diffusion in organisations. This justifies the choice and use of a longitudinal case study method and the various data collection methods described.

**Method**

The initial focus was to understand the system, its development and its application. The interplay between the context, the change process and content of the change, highlighted in studies about strategic changes (Pettigrew and Whipp, 1991) and operative changes (Carlsson, 2000) was used as a starting point, since the dimensions affect each other and is useful in explaining effects in a change process. Data was collected in multiple ways via overlapping activities to understand the study object as fully as possible (Meredith, 1998) over a time-period of 20 months. An overview of the various activities and the overall timescale is provided in Figure 1. The CSO was involved throughout the research period; from discussing and agreeing research methods to validation of the research and the results. Validation has taken place at several occasions as visualised in Figure 1 and is described in the final paragraph of the method section.

**Figure 1 Overview of the research process “here!”**

Initially, the process from setting the programme to management of the completed buildings was mapped and described to understand the whole erection process. The development steps of the timber system were investigated to explore how it was developed. These activities provided in-depth understanding for the construction process, the building system content, the context and the technical complexity of the system. Additional data was collected through interviews with people working in the process, supported by a review of relevant documents, including construction schedules and technical drawings. Nine individuals were identified, based on their knowledge of the TMHS. The nine interviewed were drawn from the CSO real estate company (the managing director, property manager and the construction manager), the CSO real estate development company (the business area manager, two project managers), the CSO frame supplier company (designer, technical manager) and from the head company (the marketing manager). Interviews addressed the interviewees’ function and responsibilities in the process, their interaction patterns, current performance in the process, development areas, changes from a historical perspective and barriers and success factors regarding effectiveness in the process. Interviews lasted from 40 to 65 minutes and were semi-structured, providing a structure for meaningful interviews and discussions but also flexibility (Merriam, 1994, Andersen, 1994) enabling discussion of other points of interest. A visit to the factory producing the prefabricated elements was also made to gain understanding for the manufacturing process. Findings from this first step was summarised in a company internal report containing an overview of the CSO with all business areas, followed by issues related to the TMHS; a description of the of the system; the process from initial idea to facilities management, conducted projects, problems, development areas and current projects. The report ended with summarizing reflections based on the interviews and visits covering the building sector as a whole and the TMHS in specific. These reflections mainly covered traditions and culture, trends, problems, development areas and challenges.

A live construction project was also monitored over a period of 16.5 months to validate and further understand the factors arising from the initial mapping. This provided a picture of what actually takes place within projects and allowed the opportunity for data collection that might be neglected in a historical review, reducing the risk for retrospective explanations (Voss *et al.*, 2002). On-site observations, comprising six one-day visits were conducted by one of the authors with extensive photographing, note taking and recording. This provided the opportunity to conduct a total of 39 unstructured interviews with site personnel. Those interviewed covered a wide range of people including site administrative personnel, site managers, craftsmen and supervisors. Interview questions were focused on the project and related to the performance of the project, the interviewees' work, previous and current experiences, problems and challenges related to the project. Project documents (drawings, time-schedules, meeting notes etc.) were analysed to help the researchers better understand the project and provide data for the interview questions.

Because the CSO had not sold the building system to an external organisation, some external mapping was also undertaken (the CSO has business areas that sell to private clients). Six people representing external client organisations were identified. Two were recommended by the CSO and four were identified from a review of competitors to the CSO. These individuals had, through their organisations, purchased multi-storey timber buildings several times from competitors to the CSO. Hence, they could be viewed as knowledgeable about the systems being researched. These six individuals were interviewed using semi-structured interviews lasting between 15 to 30 minutes. The interviews addressed the development of multi-storey timber buildings and factors influencing their diffusion. The external organisations and their projects were also reviewed based on information available in the public domain and contained in marketing material (homepages, movies on YouTube etc.), to provide a better understanding for the interviews. In addition to helping to validate earlier findings, this activity nuanced the results of the interviews with complementary data.

In summarizing and analysing the collected information, the scope has been narrowed down gradually. The case study presentation provides a description of how the system has developed within, and between, a series of projects. From a diffusion point of view it is relevant to show the whole diffusion process from an organisational point of view, and addresses one of the challenges identified by Rogers, namely taking a longitudinal perspective. It also provides useful insights into the systemic effects when diffusing the innovation. The second part presents the identified diffusion factors from the whole study including validation, which is a result of a number of summaries (reports and drafts). The method for this part can be related to thematic analysis (Daly *et al.*, 1997). The authors have searched for themes within the collected information, trying to identify implicit and explicit ideas within the data (Guest *et al.*, 2012) with a focus on their relevance for diffusion of systemic innovations. This interpretative process has been affected by the researchers themselves but also by all other influential activities that **h**as occurred during the research.

Validation activities formed an important aspect of the research design. After four months the data was presented to, and reviewed by, members of the CSO, comprising the project manager responsible for the manufacturing of the timber structure, the prefabrication factory production manager and the contact person for this research project. This provided valuable feedback for the CSO while also helping to identify the focus of the data analysis. After five months a draft of the research results was presented and discussed with senior research colleagues participating in the project. The academic critique helped to further focus the research findings. At six months the experiences and other collected data from the erection of the first project were overviewed and discussed with two central people in the CSO's work group for the timber system. To complete the research the results were validated with the project manager, the assistant site manager, the head designer, the development manager for housing and a project manager who had managed other multi-storey projects. This step provided additional confidence in the research results, with the various individuals confirming that the findings of the case study research were representative of their experiences. The validation reviews each lasted for approximately one hour. Combined, all of the feedback activities have enriched the research project and, as reported by members of the CSO, has provided valuable learning experiences for the future development of the system.

**Case study: Developing the system**

The CSO is a Swedish corporation with several different business areas (BA's) that are all based on timber. They are active from the very start of the construction chain (processing timber) through to the design, construction and management of rental apartments. Depending on the configuration of businesses (or a building project) the CSO can have one or several roles (for instance one BA acts as a customer to another BA acting as a supplier). Their housing products range from fully prefabricated timber family houses to individual building elements (their 'loose' products), such as pre-fabricated roof trusses. The CSO also sell products in timber that do not directly relate to construction and constantly search for and implement new products with timber as the base material. Previous experience in manufacturing small timber houses had positioned the organisation to exploit the change in Swedish regulations and to expand the business into multi-storey timber apartments. Their initial aim was to create what they refer to as an 'open building system', meaning openness to buy different parts of buildings from a variety of companies as well as their own products. Although the design and way of erecting has differed over different projects, the system can be described as consisting of prefabricated surface elements with insulation and sealing coat and some installations in the elements (described more thoroughly later). Erecting a building covers all stages in the construction process and thereby also affects a number of different parties within and outside the CSO, I e system has an inter-organisational width. To date the company has completed five multi-storey housing projects of different sizes, has three ongoing and three starting up, of which one ongoing project was monitored.

*Projects 1-5*

The first project contained three four-storey buildings with a total of 24 apartments constructed in 2003-2005. The floors were prefabricated and the rest of the system was manufactured on site in a field factory. The project was relatively successful, but a major

problem was that rain damaged parts of the last building to be erected, and these had to be replaced and repaired at additional cost. The CSO did not use weather protection. The next project, Project no. 2, was a five-storey building with 29 apartments carried out in 2006-2008. The building system was virtually the same as in the first project. A major contractor was hired with the only demand that the house should be built using timber. In this project the CSO only delivered the base material (timber components) and the manufacturing was, once again, carried out on site in a field factory.

Before project no. 3 started the CSO participated in a pilot project to create a prefabricated, lean-inspired, timber building system. A trade organisation, a large technical consultant firm, large contractors and a smaller construction company participated in the project. Combined the partners represented different perspectives of the construction process to create a well-functioning system. One of the largest municipalities in Sweden became interested in the system and this resulted in the award of a contract for project no. 3, running between September 2010 and July 2012. The project comprised four five-storey buildings comprising a total of 68 apartments. The CSO's internal real estate development company and their internal business that handled the rental apartments were responsible for ordering the buildings, despite the fact that they considered the project to be too large and risky. A contractor was hired and the timber elements were fabricated internally by the CSO. Before production started on the site a few modules were built and sound tested, which also allowed the assembly crew to test it for a period of two days. This provided useful feedback and learning for the assembly crew, as a result of which a number of construction details were adjusted to improve constructability in the workplace. However, once on site the system worked poorly and too much additional work was required. This was traced back to misunderstandings about the building system and its (incorrectly) perceived capacity. This was made worse by a variety of people making (contradictory) decisions at different stages in the project. The lean construction philosophy also collided with the thoughts and ideas of the architects, resulting in further process waste. Both the technical manager and the head designer stated that the system would have needed several construction projects to work through the challenges to become functional. For example, the project material that should have been delivered floor by floor during assembly had to be delivered later through windows and door openings, which was both complicated to achieve and expensive. In addition, the system could not handle the imposed forces from the temporary weather protection system. Therefore it had to be re-designed, adding extra cost and time to the project.

Project no. 4 comprised three four-storey buildings with a total of 36 apartments. It was carried out between 2011 and 2013. This time the focus by the CSO was on the management of the project rather than the system (as in the previous projects). The floors were redesigned and construction details were changed. The façade walls were built on site and the bearing walls and floor were prefabricated off site. Although this was inefficient from a prefabrication point of view, it was the solution that was used. The system worked well from a sound, fire and assembly perspective. The next project, project no. 5, carried out during 2013-2014 consisted of two buildings with four storeys and a total of 24 apartments. In this project the party wall was modified further. The



project was an important test of the system for the monitored project (Project no. 6) and the system was price competitive for the first time. Representatives from the CSO had a one-day review of drawings; fastenings etc. and CSO representatives visited the site on different occasions to support the project. The assembly worked well except for rain and wind that complicated the assembly of the last building. Plastic foil was successfully deployed to protect the work from the elements and a key learning experience was to use weather protection for all future projects. One mistake was that the façade sheets were mounted on the prefabricated elements incorrectly in the factory. The necessity to control logistics on the site, i.e. on site inventories being delivered and installed in the order intended, was another experience gleaned from the study. There were still clashes between different trades, for example the scaffolds were raised as the building was erected which created stress for the carpenters. Furthermore, holes for services etc. was not prefabricated and therefore had to be formed on the site; a function missing from the specifications and quotes.

*Project 6 - The monitored project*

In the monitored project the latest version of the system was used. It was regarded as particularly important by the CSO since it would show if the organisation could handle large projects. One six-storey building with 50 apartments and two five-storey buildings with 20 apartments comprised project no. 6. Apartment-sizes varied between one-bedroom to three-room units. The buildings were quite traditional in design, despite having irregularly placed bay windows and façade sheets in varying red nuances on the larger building. The other buildings have balconies and are covered externally with render. This time, the CSO was responsible for managing the whole project from start to completion, including the sale of the apartments. It sub-contracted the erection work to a total of 30 different subcontractors, ranging from assembly of the house through to cleaning. The CSO fabricated the main elements for assembly (floors, walls etc.). Some installations (electric, plumbing etc.) were planned to be prefabricated but were, in the event, not realised. The project contained one major challenge; a physically restricted site with many buildings erected at the same time resulting in considerable logistical challenges. This time a weather protection system was used as a result of earlier experiences.

The erection of the first building proceeded without major incident. A delay of twelve days occurred but this was adjusted later in the project as deadlines were extended. Some minor and some larger mistakes stemming from the design phase occurred which led to additional work on the site. For example, incorrect measurements for the bay windows resulted in considerable extra work on site. Some beams also had incorrect measurements, but this was quickly corrected as the work developed. There were also challenges relating to personnel. The first site manager left the project due to burn out and in the end validation sessions it became clear that the project organisation was poor. With a better-developed delivery system and better site organisation the project may have been more successful, but it was found wanting with many challenges associated with the system. In addition the subcontractor handling the electrical installations went bankrupt, which created considerable additional cost to the project and additional work. During the project delays were caused by missed deliveries of materials. The root cause of these



issues was traced back to wrongly specified amounts ordered during the design phase and missed orders. Major delivery problems also occurred because one of the internal business areas managing material to the site did not meet the delivery schedules. This was reportedly due to internal lack of respect, giving external customers priority over their internal customers. Some interviewees also highlighted that the company needed to specify (and improve) their administrative processes because a lot of problems were found to relate to this issue. The main challenge being that individual responsibilities were not clearly defined at the outset of the project.

### Identified diffusion factors

In this section the main factors influencing diffusion are discussed. These factors were derived from the entire data set, comprising intelligence gleaned from interviews, observations conducted within the monitored project, analysis of documents and the validation exercise.

#### *Recognition and tradition*

A starting point for diffusion is the adoption of the innovation by actors within a social system. From a construction point of view twenty years is a relatively short time period for a building system to develop and become established. This point was stressed, in different ways, by the interviewees from the CSO and by the external interviewees. It was stated that buyers needed to feel safe with the houses in timber that are erected and that they must feel that the houses are “good”. They also needed to recognize the product and know what it is, which is consistent with other diffusion studies. Several of the interviewees accentuated the influence of tradition and the fact that concrete was dominating multi-storey housing in Sweden. Thus the majority of the market is used to this well-tried way of building, giving it a lot of perceived advantages. For example, one of the interviewees who claimed to be ‘totally reformed to timber’ wondered at first if timber really was a suitable and durable material for multi-storey buildings. According to the interviewees it is also common that the lifespan is discussed with a lot of different point of views and historical arguments. According to both interviewees in the CSO and the external interviewees many people showed an interest in timber but lacked knowledge about it. Information and communication about timber as a building material, was stated of central importance to its diffusion. Again, this is consistent with diffusion of innovations theory.

Recognition and tradition also has effects when it comes to the actual parties in the project and the tender process. According to interviewees in the CSO, the more secure the parties in the projects feel (confidence with the system), the lower the margins needed in their quoted prices. In project 6 the carpenters had, prior to the project, built small houses for the company, where much is prefabricated. This was an important factor for their efficiency in the monitored project, since they recognised the system to a large extent from the small houses they were familiar with. The carpenters stated that it took about two floors for them to learn how to build efficiently. An observation was also made that in the beginning of the project many people waited for things to do because others were in their way. Although this is a sign of poor planning and inefficiency, it was brought about by insecurity with the large number of people being seen by the CSO as a buffer

against unexpected events. As the project progressed the people working with the weather protection system and the scaffolders were removed from the project. Their tasks were subsequently undertaken by the carpenters, leading to greater resource use and less interruption to the carpenters' work flow.

*External drivers*

According to the majority of interviewees the reasons for using timber were based on political decisions and/or the desire to decrease the environmental impact of construction. One of the "external" companies erects all of their buildings in timber for environmental reasons. Only one of the external interviewees decided to erect timber-based buildings mainly due to financial reasons. Their calculated costs showed a very low level of deviation compared to actual costs, with the timber system being cost competitive with concrete. Demands in the municipality's detailed development plan were another external driver that was mentioned by the interviewees.

*Complexity in managing the system and active clients*

The craftsmen in the monitored project had not experienced any major problems in the assembly of the building. Most of the complicated work has taken place in the detailed design phase, where the emphasis was on simplifying the work for the craftsmen. In the on-site visits all craftsmen claimed that any changes had been minor compared to what they were used to in previous projects. In the validation stage it became clear that managing all parts of the system is where the challenges lay, and not in specific (individual) activities. This view was supported by the response from the external interviewees who did not perceive TMHS as complex (although it can be assumed that this relates to how well-developed the TMHS is). Coordinating all the subcontractors to get the interfaces right was a cumbersome task and one ripe for improvement. Similarly, controlling everything within the project was a task that the project managers needed to improve, given that they were ultimately responsible for the delivery of the projects. Given that none of the external interviewees saw the system as complex, there appeared to be internal challenges within the CSO relating to coordination and project control. The external interviewees highlighted the importance of knowing the systems characteristics and to be active from the start of the process in its management. In some cases they claimed to push the suppliers to develop their products further. This had led to the development of 'closed' systems as a means of controlling the project, something the CSO had not intentionally pursued.

*Financial aspects*

It has taken time for the CSO to develop a cost/price competitive building system, finally achieving it with project no. 5. Since other lines of business are profitable for the CSO it is not dependent (for now) on the return of investment of the building system. This may help to explain why the system has taken so long to evolve, even though there was support from the senior management of the CSO. Interestingly, it was the financial strength of the CSO that allowed the subcontractors to take risks (hired by the CSO on a running-fee basis), although none of the external interviewees believed that timber required more financial strength compared to other materials. External interviewees felt that timber systems were safer from a financial perspective, especially so given the

superior time for erection of the timber buildings. One important factor was that the characteristics of the system must be considered. Efforts had to be made in the start of the project to get everything right and all parties must be involved and committed from the start. In the interviews it was also stated that a larger volume of houses is needed to increase efficiency and hence achieve more competitive prices.

#### *The definition level*

Many development steps have been taken and many actors within the CSO seem to think that it is moving into a somewhat more stable phase. Emphasis is moving from the actual timber design on to other issues such as support process matters and marketing and sales. Furthermore, it is now recognised by the CSO that the system must be more defined and clarified, although they felt that getting an overview was complicated due to many drawings and details. Some interviewees suggest that the system should be presented as a catalogue with drawings and assembly instructions. Standard solutions to “pick from” could be useful for the designers and tradespeople. Examples of fine-tuning activities were also given, for instance improved structural loading. Investments have also been made during development time in equipment in the factory to handle the heavy elements and in cleaning equipment. The CSO has stated its ambition to set up a network of partners that they can work with continuously, as part of a strategic alliance. This, they feel, will be instrumental in helping to improve the quality of the system and the associated delivery process. In doing so, they aim to be able to diffuse the system more successfully in the future.

#### **Discussion**

A change in regulations can be a starting point for innovation (Gann *et al.*, 1998), and for TMHS the change in Swedish regulations was a stimulus. By executing projects and developing the system in practice the CSO has demonstrated the functionality of high-rise timber for their business and their clients. Their immediate competitors also produce well-working examples. Collectively this helps to improve recognition over time and helps to break the path dependency of the established material (concrete), as highlighted by Mahapatra *et al.* (2012). Thus competitors both depend on, and ‘help’ each other, regarding adoption and diffusion of the systemic innovation. It has also been stated that external drivers give diffusion a helpful push in the earlier stages of diffusion. As recognition increases and systems are improved and become more competitive, the push from external drivers appears to decrease. Resource consuming development over a long time period, as in this case, highlights the necessity of financial stamina. Larsson (1992), for example, noted that incremental innovations are easier to implement and can provide a quick financial return. But what is evident with this systemic innovation is that many incremental innovations (changes) are needed in the overall system, and this creates complexity and also consumes time. With systemic innovations the risk-taking (and perceived risk) is higher as many inter-related issues need to be resolved, which takes time. For the diffusion of innovations an active client is an important factor (e.g. Blayse and Manley (2004)). For the systemic innovation studied, and as stressed in the external interviews, systems in timber must be chosen in early stages of a project, the systemic innovation serving as a point of departure when defining and designing the building. This requires understanding and adaptation from the client, implying a need of active clients,

who on the other hand can be quite relaxed in the later stages of building projects, if they buy a well-defined TMHS.

However as for the CSO, having business through the construction chain is another alternative reducing reliance on clients, as it provides the ability to manage, control and develop the construction supply chain without dependence on external parties. Nevertheless, for systemic innovations there is a challenge in overviewing, coordinating and controlling the system and its parts. This can help to explain why the development of the system has been conducted in several steps (projects) with design changes in virtually all steps and a move toward a higher level of prefabrication. When reviewing the projects they have an important relation to each other, providing the next project with input to needed changes, and thereby preceding projects shapes the next. This can also be related to Murphy *et al.* (2015), and the importance of exploiting opportunities for reuse from one project to another. Using Rogers (2003) in this overview, it can be seen that there is a large amount of redefinition and restructuring in the early stages (projects) but as time moves forward and more projects are finished, it moves more against clarifying and routinising. The development has moved the CSO closer to their competitors where prefabricated and well-defined systems seem as a key factor for diffusion. Furthermore, a high level of prefabrication and standardisation provides a shorter lead-time on site, also expressed as an important advantage for timber systems. This results in a 'closed' system which on the evidence of this case study appears to favour diffusion, since it minimizes the need for interaction, changes and knowledge exchange with other parties.

According to previous research, complexity has a clear influence on the diffusion of a systemic innovation. The case study shows efforts to manage complexity, mostly in the design phase, to create a well-defined and less complicated system for the production phase (which was not well managed and where it seemed difficult for the CSO to handle all of the sub-contractors, which is in line with Winch (1998)). Furthermore, the necessity of cross functional teams, as pointed out by Widén and Hansson (2007), is evident in the findings, especially with reference to the external interviews where the necessity of participating early in the process and collaborating was accentuated. This highlighted the need to establish interfaces within the construction contracts.

Developing the system has meant development of knowledge in many ways for the CSO. Demands regarding acoustics, stability, fire and increased prefabrication have driven the design (and learning) forward. Many problems have been handled and solved in the design phase, although, as described earlier there were many issues that were only evident once the projects began the site phase. Prefabrication is one means of simplifying construction and address challenges with learning and knowledge sharing, as highlighted by Gann and Salter (2000) and Blayse and Manley (2004). However, many types of professionals are needed in the different project stages influencing diffusion, as noted by Taylor and Levitt (2005). Furthermore, the amount of knowledge flows and knowledge exchanges still influences the diffusion of a systemic innovation. However, with a more well-defined system and simplified tasks for different subcontractors diffusion could be simplified. In addition to restructuring the supply chain the CSO aim to use the same subcontractors from project to project, hence minimizing the change in organisations and



participants from project to project. Previous research has suggested that a large span, i.e. when many different boundaries are affected (Taylor and Levitt, 2005), influences diffusion. The findings show that the amount of new knowledge needed in each boundary is also influential and a suggestion is to add this dimension, as the 'knowledge leap' that comes into question in each boundary; and which has impact on choosing partners. With a larger knowledge leap the need for a strategic partnership increases.

As highlighted by Hemström *et al.* (2011) perceptions influence diffusion. As identified in the study, recognition of the innovation has a major impact, together with other factors such as time pressure and individual risk-behaviour as emphasised by for example Emmitt and Yeomans (2008). Since systemic innovations contain many interfaces this also increases the perceived risk. In previous research as in Mahapatra *et al.* (2012) and the study, it has also been identified that current traditions has a major impact on diffusion. Some actors always use concrete, others use timber. But the study shows that once experiences from the system are exchanged (in a positive manner), perceptions change and it seems vital to get doubtful actors to the point of use. It may be interesting to further investigate what affects decision-making in different parts of the diffusion process based on the issues raised by Larsen and Ballal (2005) and Larsen (2011). It is however validated in the research that the contextual setting, the communication network and broader institutional setting has impact on the diffusion as well as the concepts of awareness and peer influence. Regarding context, many contextual factors control and influence diffusion, as highlighted by Slaughter (1998). In this study environmental impact is significant, with timber perceived as environmentally friendly. This has provided a useful push from a diffusion point of view and seems to have had impact on decision makers on various levels; and it has also enabled the CSO to present the product in this way to potential customers.

A whole building system is a more complicated matter than objects studied in previous studies where individual decision-making behaviour was identified as having a major impact on the diffusion of innovations (Larsson, 1992, Emmitt, 1997). The impact of individual-decision making is still visible in parts of the project but these can be related to the magnitude of decisions made. The decision to build in timber has a larger magnitude and seems to be taken by a group of senior people. Additionally, since the aim of the CSO is to have a high level of prefabrication there is less room for individual decision making in the erection phase. Furthermore, political decisions are evident in the context of the study, which cannot be considered as individual decision-making. Altogether, these factors also point towards a need for using and developing Rogers' framework of the innovation process in organisations.

## Conclusions

This research contributes to the understanding of diffusion of a specific type of systemic innovation. From the studies of the development and diffusion of a TMHS over time, a number of interacting factors influencing diffusion and interaction have been derived. Besides getting to the right cost level, the influence of complexity dimensions and construction industry characteristics were found to be highly influential. Foreseeing all



consequences and problems that may occur seemed to be especially complicated for the CSO and this seems to be the major complexity of the TMHS. The findings highlight that building systems with a high degree of complexity (as perceived by the CSO) need to be developed through a number of projects. In different projects different parts of the system is developed. This ‘trial and error’ approach was possible because of the financial strength of the CSO and was essential to the development of the system so that risks could be kept to a minimum. In this case the risks were largely related to uncertainty and the change from domestic scale timber systems (familiar) to multi-storey systems (unfamiliar). As such the projects reported above describe a learning process for the CSO as it moves into a new market. The study also shows that controlling many steps in the construction chain provides major possibilities for diffusion, since it enables more autonomous development. The findings confirm that the project based work method, organisational variety and span influences diffusion negatively. By using the same partners and subcontractors from project to project and by simplifying the erection of the building this could affect diffusion in a positive manner.

Based on the study and by comparison with competitors, the companies working with TMHS continuously strive to manage and reduce complexity through standardized solutions, well-defined system and increased prefabrication. Although there are many different barriers that also influence diffusion, this simplifies the production phase and activities are moved upstream away from the construction site, reduce complexity and enables diffusion. This implies a transfer of knowledge from the actual projects into a continuous learning organisation that combines new and existing knowledge to the benefit of all business activities. However, the manner in which the knowledge integration mechanisms are applied and their effects require further research given the complexity in relation to systemic innovations (where many professionals, trades and organisations participate and where a considerable amount and range of knowledge must be handled). One area of further research could relate to understanding how much knowledge an organisation requires to make the ‘knowledge-leap’ to be able to successfully integrate systemic innovations within its product and project portfolios.

Studies of adoption at the product level have highlighted the importance of individuals’ innovation decision-making behaviour. For systemic innovations the decision-making process is a ‘collective’ activity with more involved parties and more decisions compared to single innovations, relating to the framework of diffusion in organisations by Rogers (2003). Due to the study approach with an extensive view of development and diffusion over several projects, it is evident that the system has been changed from project to project, showing an extensive implementation phase that is characterized by a vast amount of redefinition and restructuring. In further diffusion studies of systemic innovations, it is advisable to use this frame of reference, although this needs to be validated further. The view of studying several projects has also been useful to see patterns, supporting Rogers’ view that studying consequences has a value in diffusion studies. Diffusion is further influenced by ‘external’ factors, such as environmental and legislative compliance and ‘political’ decisions, many times giving timber a helpful push from a diffusion perspective. In this work the development of the systemic innovation also required a considerable amount of resources over a long time period, which also

required financial strength. Even so, path dependency, meaning that professionals tend to work with what they are used to and hence familiar with (a culture of tradition), was found to be a significant factor in relation to risk taking.

In this research we have focused on one organisation and its systemic innovation. This has allowed the collection and analysis of rich data over a series of development projects. Although this organisation is comparatively late to adopt multi-storey timber construction for high rise housing projects in Sweden, it does help to illustrate the challenges for organisations moving into new areas. This should be of interest to organisations in other countries starting to develop similar systems in timber. With the focus on one system and its development in one organisation come limitations. Some of these are related to commercial concerns, which meant that it was not possible to compare this organisation with a competitor. Furthermore, due to the nature of the project and the long-time scales involved with construction projects it was necessary to retrospectively study the earlier projects. This limited the potential for allowing more nuanced insights. Despite this, the case study does provide a unique insight into an organisation developing a new way of building and further contributes to our knowledge about systemic innovations.

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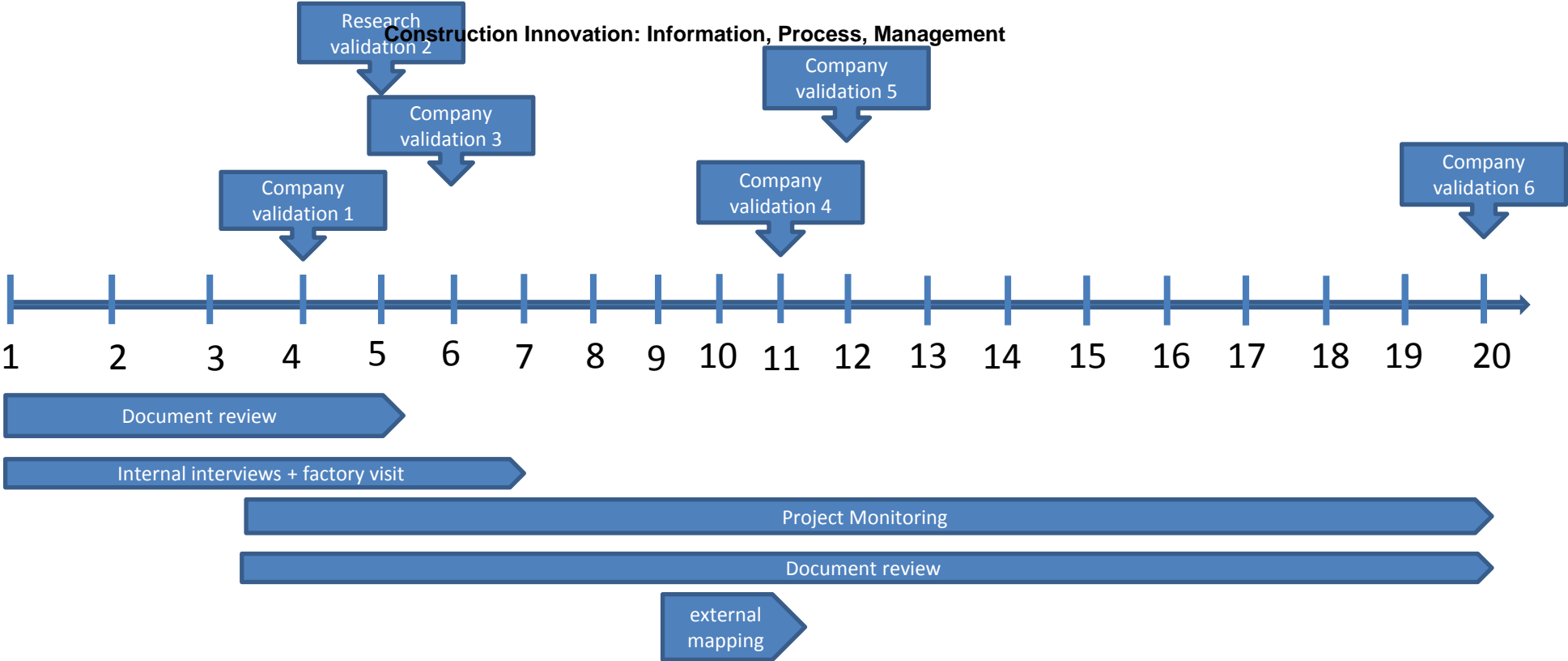


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Construction Innovation: Information, Process, Management

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Reviewers Comments to Author	Authors Response to Reviewers Comments
Language: Last line page 8, "has" not "as"	Fixed. Highlighted in yellow.
I may be too picky, but there still seems to be a confusion about what is adoption and what is diffusion. In p. 2, line 25, it is written that "diffusion process in relation to individuals"...But, the process described is not a diffusion process but a "decision-making process" of an individual or according to Rogers (2003) "innovation-decision" process. Diffusion happens with decision-making process of several individuals over time.	Good comment. The text is revised and highlighted in yellow on page 2.
Please remove reference to gender, e.g. 'He', etc.	Fixed. Highlighted in yellow.
Please use English spelling not American. Still many changes needed.	Done.
It would be useful to clarify the timeframe involved in the longitudinal case-study, and whether any intervention points were used. This just needs to be stated at the earliest opportunity, as Figure 1 clearly depicts these issues.	Clarifications have been made in the first paragraph under the heading Method, p 7, line 17-23.
Please insert a date for Roger's, page 17 line 44.	Fixed. Highlighted in yellow.